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Performance of Obsolete and Current Cultivars and Pee Dee Germplasm Lines of Cotton

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ABSTRACT

Yield and fiber quality comparisons of modern vs. obsolete cultivars and Pee Dee (PD) germplasm lines represent a measure of genetic gain for these traits and can be used to establish a base for estimating future breeding accomplishments. We evaluated 29 commercial cultivars and PD germplasm lines of cotton (*Gossypium hirsutum* L.), 12 modern and 17 obsolete, in two tests per year for a 3-yr period (1979, 1980, 1981). The soils were a Norfolk fine sandy loam (fine-loamy, siliceous, thermic Typic Kandiudult) and a Norfolk loamy sand at Florence, SC. We sought to determine what genetic improvements the new cultivars and germplasm lines had compared with the obsolete ones. Two modern cultivars, McNair 235 and SC-1 (a PD cultivar with extra fiber strength genes) produced 399 kg ha^{-1} more lint than the obsolete cultivar, Earlistaple 7, and 522 kg ha^{-1} more than the PD germplasm Line F. The rate of gain in yield of modern compared with obsolete cultivars and PD germplasm lines was 10.5 and 15.1 kg ha^{-1} yr^{-1}, respectively. The actual rate of gain in related PD germplasm lines was 20.6 kg ha^{-1} yr^{-1}. A regression analysis of the average yields in South Carolina and the South Atlantic states from 1961 through 1987 showed that yields have significantly increased at the rate of 8.0 and 9.4 kg ha^{-1} yr^{-1}, respectively. These data show that cotton breeders have made continuous progress in improving lint yield, without sacrificing fiber quality. This trend can be expected to continue. Simultaneous improvements in lint yield and fiber strength can be expected if emphasized in breeding programs.

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INCREASED PRESSURE is being placed on cotton breeders to develop cultivars that meet the requirements of growers for high yield potential and the demands of the textile industry for improved fiber quality, particularly extra fiber strength. The negative genetic relationship between extra fiber strength and low lint yields has presented a major breeding problem; however, Culp (1981), Culp and Harrell (1977), Culp et al. (1985b), and Harrell et al. (1974) reported successes of increasing lint yield while retaining a significant amount of fiber strength from Beasley's (1940) triple hybrid. Culp et al. (1979) suggested that genetic linkages between lint yield and extra fiber strength genes have been broken and predicted that simultaneous improvements in lint yield and fiber quality could

Abbreviations: HVI, high volume instrumental system; PD, Pee Dee.

be expected more frequently from a wide array of diverse germplasms crossed with PD germplasm. Green and Culp (1990a) showed that the PD cultivar SC-1 contributed both yield and yarn strength improvements to progeny, providing evidence of the breakup of unfavorable linkages. In addition, Green and Culp (1990b) reported success in the simultaneous improvement of yield and fiber strength in crosses between PD lines and Delta-type cultivars.

Miller (1977) and Reddy et al. (1987) listed a number of researchers who have reported that U.S. cotton yields have plateaued or even declined during the 1960s and 1970s, even though production technology had improved significantly. Meredith and Bridge (1982) reported that weather caused large yield fluctuations, but it was not responsible for yield decline during the period. Reddy et al. (1987) reported that the exact causes for yield decline have not been identified; however, they suggest that a complex interaction of environmental and management factors may be responsible. Furthermore, with limited data available, they suggest that yield decline, particularly in the Southeast and mid-South, may be attributed to poor insect control and increased ozone levels.

A survey (Meredith, 1980) of U.S. cotton breeders indicated that the primary objective in breeding was lint yield improvement; however, cotton producers often claim that cultivars are running out and causing the decline in yield. Meredith and Culp (1979) refuted this contention by comparing the yields of three age versions of four popular cultivars in Mississippi and South Carolina tests and by demonstrating that significant yield changes did not occur in any cultivar. Therefore, the question arises: Are there genetic gains in lint yield and fiber quality that can be attributed to current compared with obsolete cultivars or germplasm lines?

Several workers have compared performance of obsolete and current cultivars for yield and quality under high yielding conditions. In the Mississippi Delta, Bridge et al. (1971) and Bridge and Meredith (1983) reported that genetic gain in lint yield improvements averaged 10.2 and 9.5 kg ha^{-1} yr^{-1} in 1968 and 1969, and 1978 and 1979, respectively. Hoskinson and Stewart (1977) compared 'Deltapine A' and 'Carolina Dell' with four modern cultivars in Tennessee and found that both obsolete cultivars produced significantly less lint and matured later than the lowest yielding modern cultivar. Using their data and regressing lint yield on the approximate year that each cultivar was released, we estimated the genetic gain at 7.2 kg ha^{-1} yr^{-1} in yield improvement of modern compared with obsolete cultivars. Since 1939, Bassett and Hyer (1985) estimated genetic gain in lint yield of the Acala cottons in California, at 8.0 kg ha^{-1} yr^{-1}. They also found that fiber strength has steadily increased throughout the 40-yr period and micronaire has remained in a relatively narrow but desirable range since the release of 'Acala 4–42' in 1949. Meredith and Bridge (1982) also determined the genetic gain in cotton yields by three methods of adjusting average lint yields as 7.74 kg ha^{-1} yr^{-1} on the basis of yield of the check cultivars, 7.02 kg ha^{-1} yr^{-1} for covariance, and 0.74% for the percent deviation from the check. They suggested that cotton breeders have made continuous progress in increasing the yield of cotton and that this trend will probably continue.

Improved PD germplasm lines and cultivars with high yield potential and extra fiber strength were also developed during this period (1945 to present) when rapid genetic gains in lint yield were being made in cotton cultivars. The objectives of this study were to (i) determine the rate of genetic gain in lint yield of modern over obsolete PD germplasm lines and cultivars grown in South Carolina, (ii) compare actual yields of South Carolina cotton, (iii) compare these findings with those of previous studies, and (iv) suggest progress that might be expected in the simultaneous improvements of lint yield and fiber strength in upland cotton.

MATERIALS AND METHODS

To compare the rate of gain in cotton yields in South Carolina with those in the rest of the USA, a regression analysis was run on the average lint yields by states from 1866 through 1987 (USDA Annual Agricultural Statistics). Lint yields were divided into three periods—1866 through 1935, 1936 through 1960, and 1961 through 1980—to correspond to a similar breakdown of U.S. cotton yields by Meredith and Bridge (1982). In addition, we studied the period from 1961 through 1987 for influence of new cultivars on lint yield.

To measure the genetic rate of gain in yield, 29 cultivars and PD germplasm lines (12 modern and 17 obsolete) were evaluated. These cultivars and germplasm lines represent the release period of 1945 through 1978, spanning 30 yr of cultivar development. The cultivars were chosen for their performance in southeastern yield trials (Alabama, Georgia, North Carolina, and South Carolina) and commercial production in South Carolina. The PD germplasm lines represent a series of yield improvements without a recent decrease in fiber strength or other quality factors. Most of the cotton acreage in South Carolina was planted to Coker cultivars during this period.

Seed of the obsolete and current PD germplasm lines are maintained in the Pee Dee cotton production program at Florence, SC. Seed of the cultivars were obtained from various seed companies. A reserve of the original release of 'Coker 201', 'Coker 310', PD 2165, and SC-1 seed was stored (Culp and Harrell, 1973). Each year, ≈1 kg of seed is removed from each reserve and planted in semi-isolation to furnish an adequate supply of fresh planting seed of these checks for the coming year. In 1978, seed of all test entries were increased at Florence to obtain uniform quality planting seed for all tests.

The modern and obsolete germplasm lines and cultivars, along with the high quality check cultivar, Acala SJ-5, the stripper cultivar, Paymaster 303, and the fiber quality check without triple hybrid ancestry, PD 4461 (Culp and Harrell, 1979b), were compared in two tests in the years 1979, 1980, and 1981. Each year, one of the tests was grown on Norfolk fine sandy loam at the old Pee Dee Experiment Station farm in Florence County. The other test was grown on a Norfolk loamy sand at the new Pee Dee Research and Education Center farm in Darlington County. The experimental design was a randomized complete block with four replicates. Plots were two rows, 1.9 m wide and 10.6 m long.

A 25-boll sample of unweathered, open bolls from the middle of the fruiting zone of the plants in each plot was handpicked from four replicates of each test to obtain boll, seed, fiber, and yarn properties. Samples from two replicates (Replicates 1 and 3, or 2 and 4) were combined at ginning to make two 50-boll samples of each entry for fiber and spinning tests.

Boll sample data were: (i) lint percentage = weight of lint ginned from the samples of seed cotton, expressed as a percentage of the weight of seed cotton; (ii) boll weight = seed cotton per boll (g); and (iii) seed index = weight of 100 seed (g).

In 1979, fiber and spinning properties were determined by the USDA Cotton Quality Laboratories at Knoxville, TN, as follows: (i) 50% span length = length, mm, at which 50% of the fibers are this length or longer; (ii) 2.5% span length = length, mm, at which 2.5% of the fibers are this length or longer; (iii) fiber strength (T_1) = (kN m kg^{-1}) necessary to break the fiber bundle with the jaws of the testing instrument (Stelometer) set at 3.2 mm apart; (iv) fiber elongation (E_1) = the percent elongation at the break of the center 3.2 mm of the fiber bundle measured for T_1 strength on the Stelometer; (v) micronaire reading = fineness of the fiber measured by the Micronaire and expressed in standard micronaire units; and (vi) yarn tenacity = force (kN m kg^{-1}) required to break a skein of 27-tex yarn in small-scale tests as described by Landstreet et al. (1959, 1962).

In 1980 and 1981, fiber and spinning properties were determined by the USDA-AMS Cotton Testing Laboratory at Clemson, SC, with the HVI system as follows: (i) upper-half mean length = the length, mm, of the one-half of the fibers, by weight, that contains the longer fibers; (ii) fiber strength (T_1); and (iii) micronaire reading = similar to above, except that HVI was used for the measurements; and (iv) yarn tenacity = similar to above tests, except HVI measurements of fiber strength were used to set the spinning frame.

Test plots were harvested once in 1979 and 1980, and twice in 1981 with a two-row spindle-type cotton picker to determine seed cotton yields. The percent seed cotton obtained at first picking was used as an indication of cultivar maturity. Lint yields were calculated from seed cotton yields × lint percentage.

Yield components, bolls per meter squared, seeds per boll, and lint per seed were estimated using formulas suggested by Maner et al. (1971) and Ramey and Worley (1973).

RESULTS AND DISCUSSION

Lint Yields 1866 to 1935

During this 70-yr period average lint yields in the South Atlantic states (Georgia, North Carolina, and South Carolina) increased at the rate of 1.8 kg ha^{-1} yr^{-1}, ranging from 1.1 kg ha^{-1} yr^{-1} in Georgia to 2.7 kg ha^{-1} yr^{-1} in North Carolina. Yields in the southeastern states (Alabama, Georgia, North Carolina, South Carolina, and Tennessee) also increased from 1866 to 1920. This increase is attributed to the influence of state land grant colleges, established by an act of Congress in 1862, on improved farming practices and new cultivars developed and distributed by new commercial seed companies. Bridge and Meredith (1983) reported a similar trend in Mississippi cotton yields during this period. Yields declined or plateaued, however, across the southeastern states from 1920 through 1935 because of the destructive invasion of the boll weevil, *Anthonomus grandis* (Boheman). Bridge and Meredith (1983) noted a similar decline in Mississippi. Miller (1977) pointed out that from 1866 to 1936 the national average yield of upland cotton fluctuated around a mean of 213 kg ha^{-1} yr^{-1} of lint with no upward or downward trends.

Lint Yields 1936 to 1960

Yields increased in the South Atlantic states during this period at the relatively slow rate of 4.0 kg ha^{-1} yr^{-1}, ranging from 1.2 kg ha^{-1} yr^{-1} in North Carolina to 7.5 kg ha^{-1} yr^{-1} in Georgia. Problems with insect control (particularly during rainy weather), lack of supplemental irrigation during dry periods, and excessive boll rot during wet harvesting seasons accounted for low yields some years in this area. Meredith and Bridge (1982) reported that national cotton yields rose rapidly from 1936 through 1960, with an average increase of 10.4 kg ha^{-1} yr^{-1}. These rapid yield increases were attributed to the movement of cotton onto more productive soils and utilization of technological advances in production, such as the use of higher-yielding cultivars, commercial fertilizers, irrigation, effective pesticides, skip-row culture, and mechanization (Miller, 1977).

Lint Yields 1961 to 1980

Although much new technology was introduced in cotton production from 1961 through 1980, yield increases in the South Atlantic states slowed to 2.4 kg ha^{-1} yr^{-1}, ranging from -1.2 kg ha^{-1} yr^{-1} in Georgia to 2.4 kg ha^{-1} yr^{-1} in South Carolina. Meredith and Bridge (1982) reported a slight decline in national cotton yields at the rate of -0.9 kg ha^{-1} yr^{-1}. Reddy et al. (1987), choosing the period of greatest yield decline (1964–1980) estimated that average U.S. cotton yields decreased at the rate of 2.2 kg ha^{-1} yr^{-1}. They reported declining yields in all major cotton states, ranging from 11.7 kg ha^{-1} yr^{-1} in Mississippi to 0.4 kg ha^{-1} yr^{-1} (not significant) in South Carolina. Concern with these declining yields has produced numerous hypotheses but exact causes have not been identified.

Lint Yields 1961 to 1988

A regression analysis of the average lint yields in the South Atlantic states and South Carolina from 1961 through 1987 shows that yields have actually increased at the rate of 9.4 and 8.0 kg ha^{-1} yr^{-1}, respectively, as a result of all technology. We noted large average yearly yield increases in most southeastern states from 1961 to 1988. Furthermore, we calculated the average rate of gain in national cotton yields from 1961 to 1968 as 5.6 kg ha^{-1} yr^{-1}. Reddy et al. (1987) suggested that a shift in yield trends might be occurring when they found an upward trend in national cotton yields of 8.5 kg ha^{-1} yr^{-1} during the short period from 1981 to 1986. Yield gains in the South Atlantic states (1961–1987) of 9.4 kg ha^{-1} yr^{-1} suggest that the period from 1961 to 1980 may have been too short a period to establish yield trends in cotton.

Regardless of the nature and cause of decline in cotton yields, cultivar instability has received major criticism from producers. Meredith and Bridge (1982) showed that yield decline could not be attributed to poor performance of cultivars and that breeders have produced a wide array of cultivars, primarily with improved yields, since the early 1900s. Our data will support their findings.

Table 1. Performance of obsolete and current cotton cultivars and Pee Dee germplasm lines for yield and yield components.

Cultivar or germplasm line	Year released or first tested	Lint yield	First pick	Lint	Boll wt.	Seed index	Calculated yield components: Boll m^{-2}	Seeds $boll^{-1}$	Lint $seed^{-1}$
		kg ha^{-1}	—— % ——		—— g ——		—— no. ——		mg
McNair 235	1978	1302	80	40.6	6.04	10.7	53	34	73
SC-1	1977	1284	81	40.0	5.76	11.3	56	31	75
Coker 304	1975	1242	80	41.6	6.09	10.7	49	33	76
Coker 310	1969	1231	78	41.4	6.06	10.7	49	33	76
McNair 220	1976	1228	78	39.8	6.24	11.1	49	34	73
Stoneville 213	1962	1212	76	39.1	5.90	10.8	52	33	69
Coker 201	1966	1210	78	39.6	6.33	11.4	48	34	75
Deltapine 16	1967	1200	78	39.9	5.99	10.4	50	35	69
PD 9223	1970	1180	81	40.4	5.63	11.3	52	30	77
PD 875	1976	1174	83	40.2	6.55	11.7	45	34	78
PD 695	1976	1161	83	38.6	5.76	10.2	52	35	64
PD 0113	1971	1135	77	38.9	6.13	11.4	48	33	73
PD 8619	1969	1130	75	38.0	6.00	11.2	50	33	69
PD 4381	1965	1121	78	37.6	6.16	11.8	48	32	71
PD 4398	1965	1100	82	37.5	5.72	11.6	51	31	70
PD 2165	1963	1088	80	39.2	6.39	12.1	43	32	78
PD 0111	1971	1077	76	38.0	6.00	12.3	47	30	75
AC 241	1962	1040	81	39.6	6.22	12.0	42	31	79
PD 3246	1964	1004	77	37.7	6.63	12.5	40	33	76
PD 3249	1964	990	79	38.8	6.48	12.8	39	31	81
CE 260	1960	944	74	38.4	7.24	14.4	34	31	90
AC 235	1960	917	79	39.1	6.88	12.9	34	32	83
Earlistaple 7	1945	903	78	37.2	6.56	12.8	40	32	76
FTA	1958	881	80	34.3	6.13	13.3	42	30	69
FJA	1958	821	76	34.1	5.83	12.7	41	30	66
Paymaster 303	1978	811	72	38.3	6.67	12.2	32	34	76
PD 4461	1967	780	71	39.8	4.90	10.6	40	28	70
F	1952	762	76	32.8	5.47	12.7	42	29	62
Acala SJ-5	1978	718	72	38.1	6.64	12.0	28	34	74
LSD (0.05)		51	3	0.5	0.21	0.3	—	—	—
CV, %		7.8	4.1	1.6	4.2	2.6	—	—	—

Obsolete vs. Modern Cultivars

The first southeastern cultivar, SC-1 (Culp and Harrell, 1979c), with extra fiber strength genes from Beasley's (1940) triple hybrid, produced significantly more lint than that of all other related PD germplasm lines (Table 1). The average yield of SC-1 was equivalent to that of McNair 235, the highest yielding currently grown southeastern cultivar in our test (Table 1). McNair 235, developed from the cross of Coker 201 × PD 2165, produced the highest lint yields in South Carolina tests and 'DES-56', developed from the cross of 'Stoneville 213' × PD 2164 (Bridge and Chism, 1978), produced comparable lint yields in Mississippi (Bridge and Meredith, 1983). PD 2165 and PD 2164 are sister lines developed from the cross of AC 239 × FJA 348, two breeding stocks in the basic PD germplasm pool (Culp and Harrell, 1979a; 1980). High yield potential and early maturity were the major criteria of selection in the development of McNair 235 and DES-56, rather than extra fiber strength. Comparisons of lint yield and percentage seed cotton harvested at first picking (Table 1; Bridge and Meredith, 1983) of both cultivars with the parents suggest that significant progress was made in the improvement of both characters. Also, it can be deduced that improvements in lint yield and earliness can be attributed to the introduction of new genes for these two characters from the PD germplasm pool through hybridization and selection.

A regression analysis of all the lint-yield data on cultivars and PD germplasm lines (Table 1) shows that

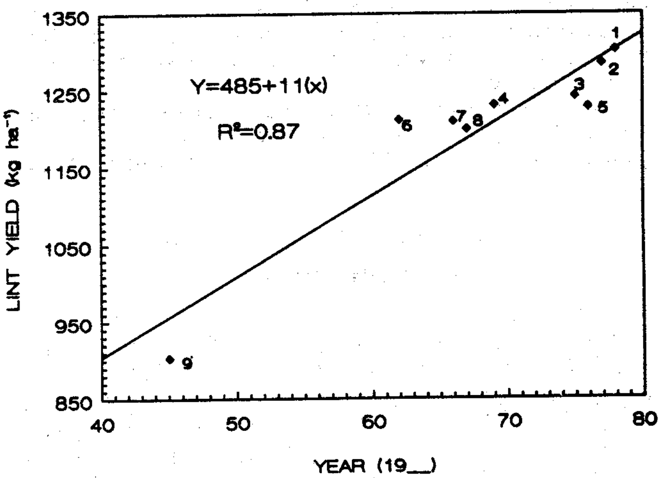

Fig. 1. Regression of current and obsolete cultivars (1 = McNair 235, 2 = SC-1, 3 = Coker 304, 4 = Coker 310, 5 = McNair 220, 6 = Stoneville 213, 7 = Coker 201, 8 = Deltapine 16, and 9 = Earlistaple 7) of cotton grown at the Pee Dee Research and Education Center, Florence, SC in 1979, 1980, and 1981.

lint yields increased at the rate of 9.2 kg ha^{-1} yr^{-1}. When Earlistaple 7 is selected as the representative of the oldest obsolete cultivar tested and Acala SJ-5 and Paymaster 303, which are not adapted to this region of production, are excluded from the analysis, lint yields have increased at the rate of 10.5 kg ha^{-1} yr^{-1} (Fig. 1). These data are in excellent agreement with

Table 2. Performance of obsolete and current cotton cultivars and Pee Dee germplasm lines for fiber properties and yarn tenacity.

Cultivar or germplasm line	Year released or tested	Span length 50%	Span length 2.5%	Upper half mean	Strength T_1	Elongation E_1	Micronaire	Yarn tenacity
		mm	mm	mm	kN m kg^{-1}	%		kN m kg^{-1}
McNair 235	1978	13.7	27.4	27.4	227	7.8	5.1	127
SC-1	1977	14.7	27.9	29.0	242	8.6	4.9	146
Coker 304	1975	14.2	28.9	30.0	230	8.0	4.9	136
Coker 310	1969	14.7	29.2	29.2	232	7.6	4.9	140
McNair 220	1976	14.2	27.4	27.7	233	7.7	5.1	134
Stoneville 213	1962	14.0	27.4	28.4	215	9.6	5.2	122
Coker 201	1966	14.7	28.2	28.4	212	8.0	5.1	125
Deltapine 16	1967	14.5	28.4	28.4	220	8.0	5.3	124
PD 9223	1970	14.5	28.4	29.0	248	6.9	5.0	146
PD 875	1976	13.7	26.9	27.9	221	9.4	5.2	128
PD 695	1976	13.7	27.7	28.4	235	7.8	4.8	139
PD 0113	1971	15.0	28.7	29.0	239	7.0	4.9	148
PD 8619	1969	15.0	29.0	29.0	248	9.5	4.8	147
PD 4381	1965	15.0	29.0	29.0	241	7.9	4.6	145
PD 4398	1965	14.7	28.7	28.4	255	7.0	5.0	147
PD 2165	1963	14.7	28.7	28.2	259	6.7	5.1	144
PD 0111	1971	15.2	29.4	30.0	262	8.0	5.0	150
AC 241	1962	14.2	27.4	28.4	253	6.5	5.1	148
PD 3246	1964	15.0	30.0	30.7	253	6.9	4.7	159
PD 3249	1964	14.7	28.4	29.0	252	6.0	5.1	148
CE 260	1960	15.0	29.0	29.5	259	7.4	5.4	136
AC 235	1960	14.7	28.2	28.4	251	6.9	4.9	144
Earlistaple 7	1945	15.0	31.2	30.2	252	6.6	4.8	152
FTA	1958	15.8	31.5	32.3	288	6.2	4.6	166
FJA	1958	15.2	31.0	33.0	281	6.3	4.6	159
Paymaster 303	1978	13.7	27.2	26.4	224	8.1	4.8	120
PD 4461	1967	14.0	27.9	28.7	243	9.4	4.8	139
F	1952	16.3	32.5	32.5	298	6.6	4.5	170
Acala SJ-5	1978	15.2	29.2	28.7	262	7.6	4.6	156
LSD (0.05)		0.5	0.7	0.7	9	0.6	0.1	4
CV, %		2.7	1.8	2.4	5.0	7.8	2.9	2.0

those of Bridge et al. (1971) and Bridge and Meredith (1983) of 10.2 and 9.5 kg ha^{-1} yr^{-1} in cultivar improvement, respectively, in Mississippi. Thus, improving cultivars for lint yield and early maturity in the South Atlantic states parallels similar progress by cotton breeders in the Mississippi Delta.

Obsolete vs. Current Pee Dee Germplasm Lines

Since 1966, the major period of recent cultivar development, Culp (1981), Culp and Harrell (1977), Culp et al. (1985a), and Harrell et al. (1974) have released a series of PD germplasm lines with improved lint yields while retaining a major portion of the fiber strength of Beasley's (1940) triple hybrid. Average lint yield (Table 1) of SC-1 (Culp and Harrell, 1979c), the first upland commercial cultivar released from this interspecific hybrid breeding program in 1977, was 522 kg ha^{-1} greater than that of the original germplasm Line F (Culp and Harrell, 1974). This value is comparable with the maximum lint yield difference of 672 kg ha^{-1} between the highest yielding current cultivar and the lowest yielding obsolete cultivars tested in 1967 and 1968, and 1978 and 1979 in Mississippi (Bridge et al., 1971; Bridge and Meredith, 1983). Nevertheless, Line F was considered a major genetic accomplishment (Culp and Harrell, 1974). Line F resembled upland cotton because it averaged 42 bolls m^{-2} (Table 1). Unfortunately, when compared with modern upland cotton, the bolls were small, seeds were large, and lint percentage was extremely low, but fiber strength and yarn tenacity were very high (Table 2). Culp and Harrell (1975) pointed out that these undesirable agronomic characteristics persisted through two cycles of modified intermating and selection, but were overcome partially with the introduction of high lint percentage from C 6–5 into the basic PD germplasm pool.

Actual lint percentages of the breeding stocks AC 235, AC 241, and CE 260 were raised ≈6% (Table 1) and lint percentage has been of minor breeding importance in successive hybridizations (Culp et al., 1979). In addition to high lint percentage, C 6–5 also contributed unusually large bolls and seed (CE 260 and AC 235, Table 1), which enhanced the undesirable boll size/seed size ratio exhibited by Line F that may have delayed boll maturity (Table 1). Boll and seed size were reduced significantly by two generations of selection (AC 241, Table 1); however, large bolls and seed were a persistent problem with most successive germplasm lines.

Culp et al. (1979) attributed the high yield potential of SC-1 (Coker 421 × PD 4398) to greater prolificacy of smaller bolls (Table 1). Although PD 4398 had significantly smaller bolls than PD 2165 (fiber quality check since 1968), the reduction in boll size of SC-1, and particularly PD 9223 (Coker 421 × PD 2164) (Table 1) probably came from the Coker 421 parent. Therefore, our data suggest that increased yield potential can be attributed to higher lint percentages and more bolls per plant. Early maturity may result in the harvest of more cotton in most years.

A regression analysis of the average yields of all PD germplasm lines by the year first tested (F_5 generation) shows that lint yields have increased at the rate of 13.8 kg ha^{-1} yr^{-1} (Fig. 2). If we exclude PD

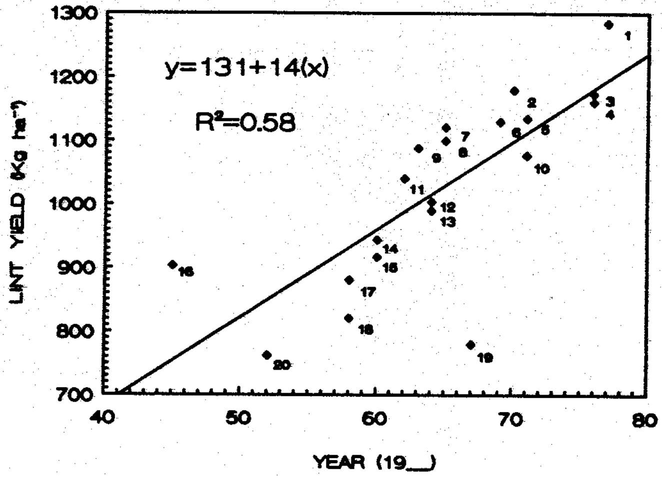

Fig. 2. Regression of current and obsolete PD germplasm lines and cultivars [1 = SC-1 (H:FTA.O), 2 = PD9223 (H:AC.FJA), 3 = PD875 (Q_1-M × DSR.6–56), 4 = PD695 (Q_1:AC.NA × AC.NA), 5 = PD0113 (AC.G:AC.FJA), 6 = PD8619 (Q_1 × M), 7 = PD4381 (AC.G), 8 = PD4398 (FTA.O), 9 = PD2165 (AC.FJA), 10 = PD0111 (AC.G:AC.FJA), 11 = AC241, 12 = PD3246 (AC.FTA), 13 = PD3249 (AC.FTA), 14 = CE260, 15 = AC235, 16 = Earlistaple 7, 17 = FTA, 18 = FJA, 19 = PD4461 (Q) (Culp and Harrell, 1979b), and 20 = Line F of cotton grown at the Pee Dee Research and Education Center, Florence, SC in 1979, 1980, and 1981. Letters represent the germplasm lines and breeding stocks as follows: A = KSE (Hybrid 313) C = C6–5, E = Earlistaple, F = KPSE (Hybrid 330), G = 'Auburn 56', H = Coker 421, J = KPE (Hybrid 363), K = Triple hybrid, M = 'MODEL', N = KPE (Hybrid 482), O = Atlas, P = AHA 6–1–4, S = Sealand, and T = KPE (Hybrid 304).

4461 (No. 19, Fig. 2), a breeding line with fiber strength genes from *G. barbadense* L. rather than from Triple Hybrid (Culp and Harrell, 1979b), a more accurate rate of increase in yield of 15.1 kg ha^{-1} yr^{-1} is obtained ($y = 91.0 + 15.1X$). This rate of increase is higher than that found with current vs. obsolete cultivars; however, it is within the range of yield increases due to breeding of 5 to 17% within seven major breeding firms during a 15-yr period (Turner et al., 1976). When we analyze genetically related material in the PD program, yield increases of high strength cotton are more dramatic. A regression analysis of the average yields of related PD germplasm on the year developed shows that lint yields have increased at the rate of 20.6 kg ha^{-1} yr^{-1} ($y = -299.2 + 20.6X$). Thus, we may have made greater progress in the simultaneous improvement of lint yield and fiber quality in the PD germplasm than that measured in conventional upland cotton improvement programs.

Yield Components Responsible for Increased Lint Production

Bridge et al. (1971) suggested that recently developed cultivars with high yield potential came about through selection for high lint percentages. They also point out that most recently developed Delta cultivars have had higher lint percentages, smaller bolls, smaller seed, and higher micronaire values. Ramey (1972), using these data, suggested that higher yields of recently developed cultivars could be attributed to increased bolls per plant. Our findings with southeastern cultivars are in good agreement with these researchers. Modern cultivars developed in the South Atlantic states have higher lint percentages and more bolls per plant (Table 1), which account for higher yield potential. In addition to SC-1, current South Atlantic cultivars generally have stronger fiber and higher yarn tenacity than those of Delta developed cultivars that we tested (Table 2).

Our findings with current PD germplasm lines agree with those of Bridge et al. (1971), Bridge and Meredith (1983), Ramey (1972), and Hoskinson and Stewart (1977) that increased yield potential can be attributed to higher lint percentages, more bolls per plant, and possibly earlier maturity. Their suggestion that some yield increase may be attributed to the longer and coarser fiber of current cultivars does not apply to the PD germplasm lines. Micronaire and fiber lengths of current and obsolete PD germplasm lines have been essentially unchanged since selection shifted from extralong to medium staple cottons after 1954 (Table 2; Culp and Harrell, 1974).

Bridge and Meredith (1983) inferred that some yield increases have come about because breeders have bred current cotton cultivars resistant to verticillium wilt caused by *Verticillium dahliae* Kleb and fusarium wilt caused by *Fusarium oxysporum* Schlect. and *Fusarium vasinfectum* (Atk.) Snyd. and Hans. Our data show that SC-1 was very susceptible to the fusarium wilt-rootknot nematode [*Meloidogyne incognita* (Kofoid & White) Chitwood] complex (Harrell et al., 1974). PD-1 (Culp et al., 1985a), released in 1984, and PD-3 (Culp et al., 1988), released in 1987, with higher lint yield potential, stronger fiber, and greater resistance to the fusarium wilt-rootknot nematode complex have replaced SC-1. The impact of these high-yielding, disease-resistant cultivars with extra fiber strength on cotton yield in the Southeast will require several years of additional production (McClintic, 1989, p. 18).

We agree with Bridge et al. (1983) that cotton breeders have made continuous progress in improving lint yield and that this trend can be expected to continue. Our findings indicate that similar progress can be made in the simultaneous improvement of lint yield and fiber strength if this quality character is emphasized in the breeding program.

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